Effect of variation of mixture (wood gelam+rice husk) on bio-pellet on the value of temperature, rate, and pressure of combustion

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Abstract. The increasing demand for energy causes the depletion of fossil fuels. To overcome this, it is necessary to utilize biomass and biomass waste. This study aimed to simulate the effect of bio-pellet density on the temperature, rate, and pressure of combustion made from a mixture of gelam wood and rice husk. The method uses ANSYS simulation with a literature review. The results showed that the increasing composition of rice husks affected the decreasing combustion rate. It was due to the calorific value of the pellets making up the material, where the lower calorific value of rice husk affects the combustion rate. Pellets with a large density affect the combustion rate, extending the burning time. The pressure of pellet molding influences the density of pellets; the greater the pressure makes the fuel denser and denser. The highest combustion air pressure occurs at 100% gelam composition and the lowest at 100% husk composition. It shows that adding rice husk composition reduces the combustion pressure, and vice versa applies to adding gelam composition.

Keywords: Biomass waste, Bio-pellet, Gelam wood, Rice husk, Combustion rate

1. Introduction

The increasing demand for energy causes the depletion of fossil fuels. To overcome this, it is necessary to utilize biomass and biomass waste as alternative fuels [1]. Along with the development of renewable energy, the demands for innovation are increasing to maximize the potential for utilizing energy derived from nature for alternative energy. One of these alternative energies, namely wood pellets [2].

Wood pellets are an alternative energy source from biomass. Pellets are obtained from sawdust, shavings, and wood chips [3]. Apart from that, wood pellets can be mixed with rice straws, husks, leaf litter, twigs, or plant parts that are considered waste [4]. In addition, wood pellets can be an alternative energy source for electrical energy because they can save fossil fuels whose numbers are dwindling [5].

The advantage of wood pellets compared to other wood fuels, such as wood chips, is that they have a higher calorific value of 4.3 million cal/ton, while wood chips have a calorific value of 3.4 million cal/ton [6]. Another advantage of wood pellets compared to wood chips is that wood pellets have a higher price [7].

The most abundant plant in South Kalimantan, gelam wood, with the potential for wood production in 2006, was 55,745.78 m^3. Data from the Forestry Service of South Kalimantan Province notes that the potential for gelam production in Barito Kuala Regency per year reaches 20,000 m^3, making the district the largest producer of gelam in South Kalimantan.

Kayu Gelam, or Melaleuca cajuputi is a species that grows naturally in swamp forests and is found abundantly in peat swamp forests of South Kalimantan [8]. Gelam wood has high specific gravity and has the potential to be used as raw material for charcoal and wood pellets [9]. The demand for wood pellets from year to year always increases, driven by policies to reduce greenhouse gas emissions and increase the use of renewable energy [10].

There is an imbalance between the production and consumption of wood pellets to meet demand. It can be added to waste from rice straws, husks, leaf waste, twigs, or plant parts which are considered waste [11].

Currently, the utilization of rice husk waste is still very small. Rice husk waste, in general, will be burned by farmers who create pollutants in the air and can interfere with public health [12]. On the other hand, rice husk, often seen as agricultural waste, has great potential to be used as biomass energy [13]. The biomass produced by rice husks can produce solid biofuels such as pellets [14].

Husk as biomass can be used for various needs such as industrial raw materials, animal feed, and fuel [15]. For example, in the rice milling process, usually about 20% - 30% of husks can be obtained, bran between 8% - 12%, and milled rice between 50% - 63.5% of the weight of the grain [16]. The largest rice production area in South Kalimantan is Barito Kuala (Batola) Regency.

Barito Kuala (Batola) Regency is an area that has an area of 3,284 kilometers with the capital city Marabahan, is one of the regencies in South Kalimantan Province where most of the people work as farmers or are engaged in the agricultural sector. Barito Kuala Regency has the largest harvested area and rice production in South Kalimantan (Kalsel). Data from the Central Statistics Agency (BPS) of South Kalimantan Province using the Area Sample Framework (KSA) method, Batola Regency has a harvested area of 66,995 hectares. From the harvested area, Batola Regency became the largest contributor to rice production, reaching 263,000 tons more dry-milled unhulled rice (GKG) from January to September 2018.

The abundance of rice production will certainly contribute to the abundance of rice husks. The abundant availability of rice husks and gelam wood in Batola Regency makes the potential for their use as raw material for rice husk wood pellets very large [17]. The combination of gelam wood and rice husks into wood pellets can be done because pellets derived from husks have a calorific value of 3090.64 – 4049.05 cal/g [18].

In addition, the pressure in the molding can also affect the physical properties and combustion characteristics [1]. So that by varying the pellet molding pressure, it is expected to obtain wood pellets of rice husk with the best physical properties and combustion characteristics. More in-depth research is needed to find out the characteristics of wood pellets from gelam-rice husk wood [19]. The topics raised in this study are in line with the Research Master Plan (RIP) of Lambung Mangkurat University in the leading fields of wetlands and the leading topics of energy security, advanced materials, and infrastructure. The resulting gelam-rice husk pellets can be directed to applying applicable research results and play a role in providing alternative energy options to replace fossil fuels [20].

The combustion temperature of the pellet also affects the structure and changes the chemical composition and structure of the pellet [21]. According to [22], the combustion efficiency and emission performance of CFB bio pellets were tested using 2-dimensional CFB combustion modeling. The model efficiently simulates the results associated with excess air value, which is the verified main parameter. The OC combustion efficiency changes between 82.25 and 98.66% due to excess air, increasing from 10 to 116% with a maximum error of about 8.59%. The efficiency of rice husk burning changed between 98.05 and 97.56% as the operating speed increased from 1.2 to 1.5 m/s with a maximum error of about 7.60%.

CO and NOx emissions increase with increasing carbon and operating speed [23]. Increased excess air results in slightly higher levels of NOx emissions. Many combustion products occur in the upper zone due to high volatility. The temperature variations in the burning of rice husk pellets can affect the combustion properties, decrease the water content, and increase the ash content [20]. Previous studies that only discussed rice husks did not use a mixture of other materials, such as galam wood. The effect of solids on the speed and temperature of combustion in a mixture of galam wood and rice husks has not been discussed. This study aims to simulate the effect of the density of bio pellets on the speed and temperature of combustion made from a mixture of galam wood and rice husks.

2. Material and Methods

2.1. Material

Wood Pellet is a material made from wood that is compacted so that the fuel can burn for a long time. Wood pellets can also be used as alternative energy for home or industrial scale. This wood pellet is made from wood waste or parts with no economic value. So the manufacture of wood pellets can increase the selling value of this wood waste. This wood pellet has enormous potential in the industrial sector because it can be used as alternative or renewable energy that can replace current conventional materials.

Gelam is a plant that is tolerant of extreme land conditions such as acidity and high salinity [24]. Gelam wood is hardwood with a specific gravity of 0.85, durable class III and strong class II. Gelam wood is used for boats, building construction, poles, bridges, and energy wood [25] and can potentially be developed as a raw material for wood pellets and as a producer of high-quality liquid smoke [26]. Wood pellets made from gelam wood can produce a calorific value of 4100 cal/g [27]. As a raw material for wood pellets, gelam wood can be combined with biomass, such as rice husks.

Rice husk is a karyolytic hard layer material consisting of two interconnected parts, namely the lemma and palea. Rice husk results from the rice milling process, where the rice grains are separated from the husks. The husk is often called waste, so this material can be used to become biomass. Rice husk has physical properties, which include a density of 122 kg/m^3 and silica burning ash of 86.90-97.30% [28]. In South Kalimantan, the potential for rice husk waste is very large and has the potential to be used as fossil fuels in the form of solid fuels.

It should mention the time and place of research in the first part. All materials and methods that used such chemicals for analysis, treatment, and experimental design must be stated clearly and briefly. State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results. A Theory section should extend, not repeat, the background to the article already dealt with in the Introduction and lays the foundation for further work. a Calculation section represents a practical development from a theoretical basis.

2.2. Methods

This research method uses ANSYS Simulation by searching for temperature, rate, and combustion pressure variables. The formulas used in this simulation are obtained from combustion formulas that are commonly used. The percentage of gelam and husk mixture is determined as shown in Table 1.

The fuel density is the ratio between the mass of the fuel and its volume. The density of fuel affects the length of combustion time [29]; the higher the density of a material, the longer the combustion process. For the calculation of the density of the mixture, it is shown in Table 1. The wood and husk thermal conductivity values are 0.21 [30] and 0.071 [14], respectively.

Table 1. Density of mixture Gelam and Rice husk

No.	Gelam percentage (%)	Rice husk percentage (%)	The density of the mixture (kg/m^3)	Rated thermal conductivity of wood (W/m K)	Husk thermal conductivity value (W/m K)
1.	100	0	1159.67	0.12	0.071
2.	80	20	978.65		
3.	60	40	797.62		
4.	50	50	707.11		
5.	0	100	254.56		

Solid fuel combustion has several characteristics, namely: combustion rate, combustion temperature, and combustion pressure. The burning rate is the amount of wood pellet mass lost in a certain time interval. Higher combustion temperatures can increase the reaction rate and cause shorter combustion times. The combustion rate is calculated as follows:

$$\text{Burning rate} = \frac{\text{Burning pellet mass}}{\text{Burning time}} \left(\frac{\text{gr}}{\text{detik}}\right) \tag{1}$$

The wood pellet burning temperature is the temperature that occurs during the wood pellet burning process. The temperature of the wood pellet will continue to rise and reach its maximum point along with the number of parts of the wood pellet that are burned and will decrease along with the number of parts of the wood pellet that becomes ash.

Thermal conductivity:

$$Q = m \; x \; C_p \; x \; \Delta T \tag{2}$$

With $\Delta T = T_1 - T_0$

Where:

T_1 = Combustion Temperature (K)
ΔT = Difference in combustion temperature-initial temperature (K)
T_0 = Initial Temperature (K)

that,

$$\text{Combustion Temperature } (T_1) = \frac{Q}{mc_p} + T_0 \tag{3}$$

Ideal gas equation:

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^k \tag{4}$$

Combustion pressure is the pressure that occurs on wood pellets as a result of the ongoing combustion process. Combustion pressure is strongly influenced by the material being burned and the temperature that occurs during the combustion process.

Combustion pressure:

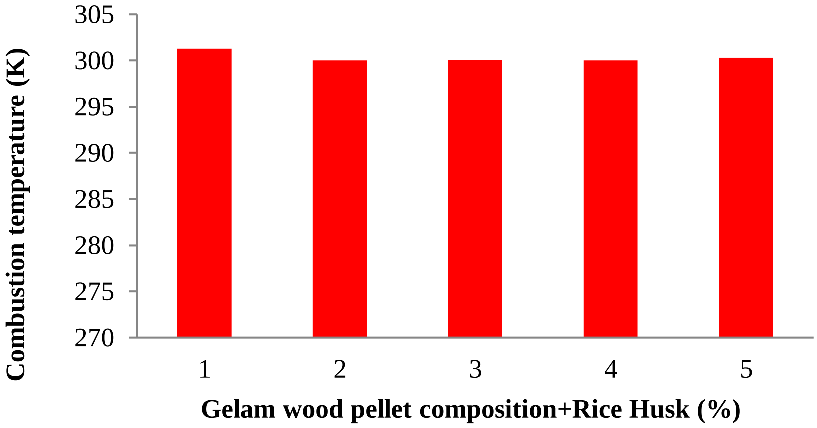
$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^k \tag{5}$$

Where:

P_1 = initial pressure (atm)
P_2 = pressure after combustion (atm)
V_1 = initial volume (m^3)
V_2 = volume after combustion (m^3)

3. Result and Discussion

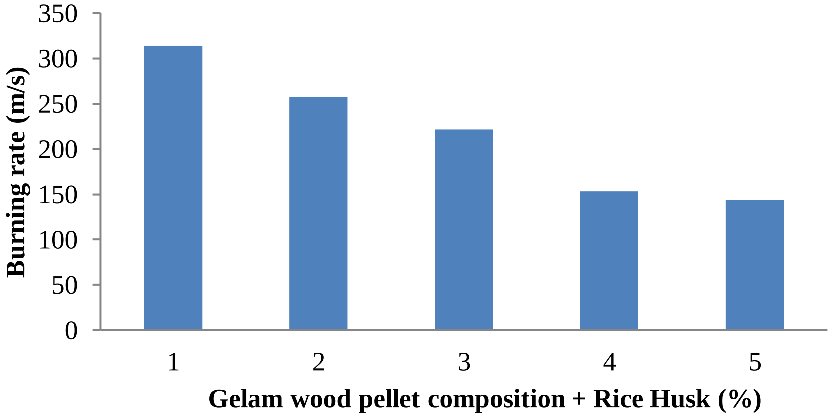
The combustion process generates heat which in turn raises the combustion temperature. When a mixture of gelam and rice husks is pelletized, then pressed and glued using an adhesive, the combustion temperature is almost the same, as shown in Figure 1. In addition, the pressure in pellet molding can also affect the physical properties and combustion characteristics [1]. So that by varying the pellet molding pressure, we get wood pellets with the best physical properties and combustion characteristics [19]. The advantage of pellet formation on two materials is that they can provide mutual benefits and cover the weaknesses of the two materials. The calorific value of low rice husks will increase when subjected to the process of pressing and adding adhesive so that the value of the combustion temperature increases.



■ Pellet composition (1. Gelam 100%), (2. Gelam 80%: Husk 20%), (3. Gelam 60%: Husk 40%), (4. Gelam 50%: Husk 50%) dan (5.Husk 100%).

Figure 1. Graph of Burning Temperature of wood pellets for rice husks

The difference in combustion temperature between gelam and husk 100% when the pellet is formed is only about ±1 K as shown in Figure 1. It can be concluded that the combustion temperature value is stable. Making pellets is very significant to increase the calorific value of combustion of mixed materials that have a low calorific value such as rice husks. Pellet raw materials can be taken from useless materials such as gelam waste and rice husk waste which are widely available around us. Gelam wood has a calorific value of 4100 cal/g [28] and rice husks of 3300 cal/g [32]. The addition of the percentage of gelam does not increase the combustion temperature as well as the addition of the percentage of rice husks; this is very beneficial when considering the lower calorific value of rice husks. Likewise, the thermal conductivity value also does not affect the combustion temperature because the thermal conductivity value in gelam is much higher when compared to rice husks, as shown in Figure 1.



■ Pellet composition (1. Gelam 100%), (2. Gelam 80%: Husk 20%), (3. Gelam 60%: Husk 40%), (4. Gelam 50%: Husk 50%) dan (5. Husk 100%).

Figure 2. Graph of the Burning Rate of wood pellets for rice husks

Figure 2 shows the relationship between variations in the mixture of gelam and husks in the composition (0-100%), where the gelam composition (100%) has the largest combustion rate value, and the burning rate decreases when the amount of rice husks increases. When the composition of rice husks increases until it reaches 100%, the value of the combustion rate decreases; this is influenced by the calorific value of the pellets making up the material. The calorific value of rice husk, which is lower than the calorific value of gelam wood, affects the combustion rate. In addition, other factors that affect the rate of pellet combustion include particle size, air flow velocity, temperature, type of fuel, pressure, oxygen concentration, and the nature of the elementary reactions that occur [28].

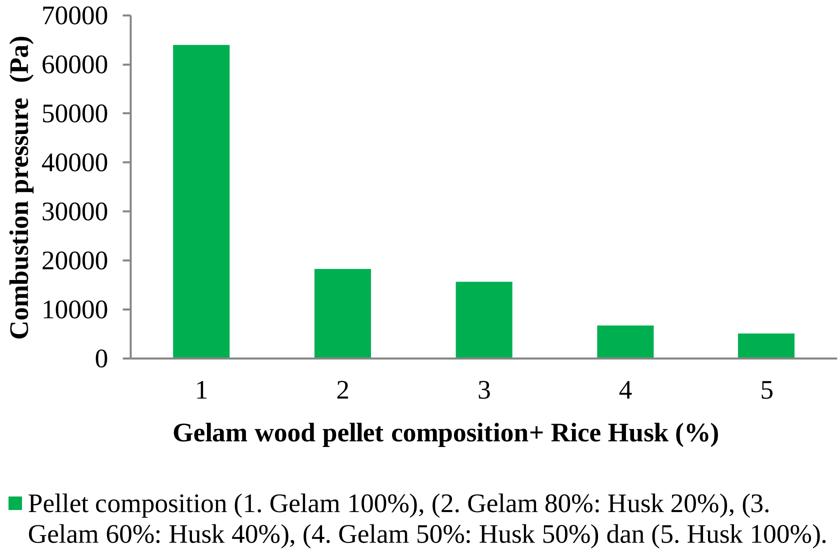
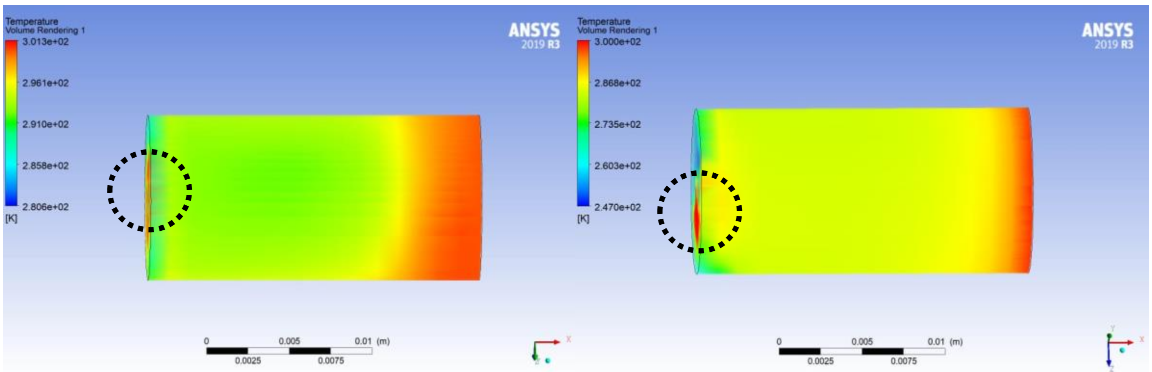
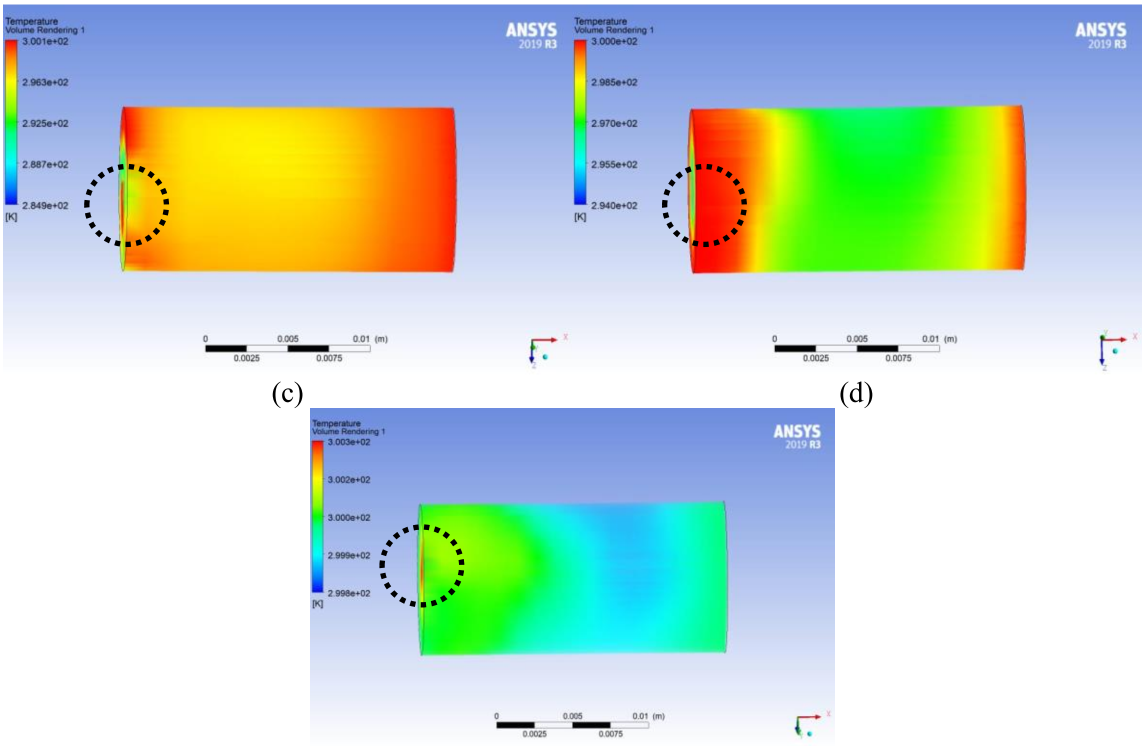


Figure 3. Graph of the Combustion Pressure of the wood-husk wood pellets

The pellet combustion pressure in the composition variations shows different values, as shown in Figure 3. The 100% gelam composition value has the highest pressure value, which decreases with increasing husk composition in the pellet composition. The high combustion pressure is caused by the high calorific value of the fuel. Combustion pressure is also influenced by grain size and pressure of wood pellet printing because it will affect the rate and direction of air flow used in the wood pellet burning process. The high combustion pressure also indicates the more complete the combustion process that occurs.



(a) (b)



(c) (d)

(e)

Figure 4. The results of the ANSYS simulation of pellet combustion temperature in the variation of the mixture (gelam wood + rice husk): (a). 100% gelam composition, (b). Gelam composition 80%: Rice husk 20%, (c). 60% Gelam Composition: 40% Husk, (d) 50% Gelam Composition: 50% Husk and (e). 100% Husk Composition

The pellet combustion process is influenced by the composition of the ingredients that make it up. In this study, two materials were used, namely gelam wood and rice husk, which have different properties. The pellet combustion temperature in the mixed composition (0-100%) is shown in Figure 4. The appearance of the simulation results shows the dominance of different colors in the composition of 100% gelam (green), 80% gelam (Yellow), 60% gelam (red), gelam 50% (green), and gelam 0% (blue). In this simulation, the combustion temperature is relatively the same; the value is not different. A good combustion temperature is a homogeneous temperature on the entire surface of the pellet, where the ignition process starts from the highest temperature on the pellet's surface. Then the temperature propagates to the closest area, until all the pellets are burned out. There is a difference in Figure 4(a-d) in the composition of 100-50% gelam; it appears the appearance of a red color (circle mark); this indicates the gelam powder gives a combustion effect with a higher heating value. The decrease in gelam in the pellet mixture indicates a decrease in calorific value, as shown in Figure 4(e).

The size of the flame affects the rate of the combustion process, where the larger the flame causes the fuel to run out faster. A good flame is if the fuel has a large combustion rate and can last longer. The simulation results show that in the 100% gelam mixture, Figure 5(a) circle marks, the flame is quite good with the best burning rate, followed by the 80-60% composition, Figure 5(a,b,c). In the 0-50% dark mixture condition, Figure 5(d,e) circle marks, the fire appears to be getting bigger, indicating the pellet burns faster so that the fuel runs out quickly. In this process, pellets that have a large density affect the rate of pellet combustion, thereby prolonging the burning time. The pressure of pellet molding influences the density of pellets; the greater the pressure, the denser the fuel and the greater the density.

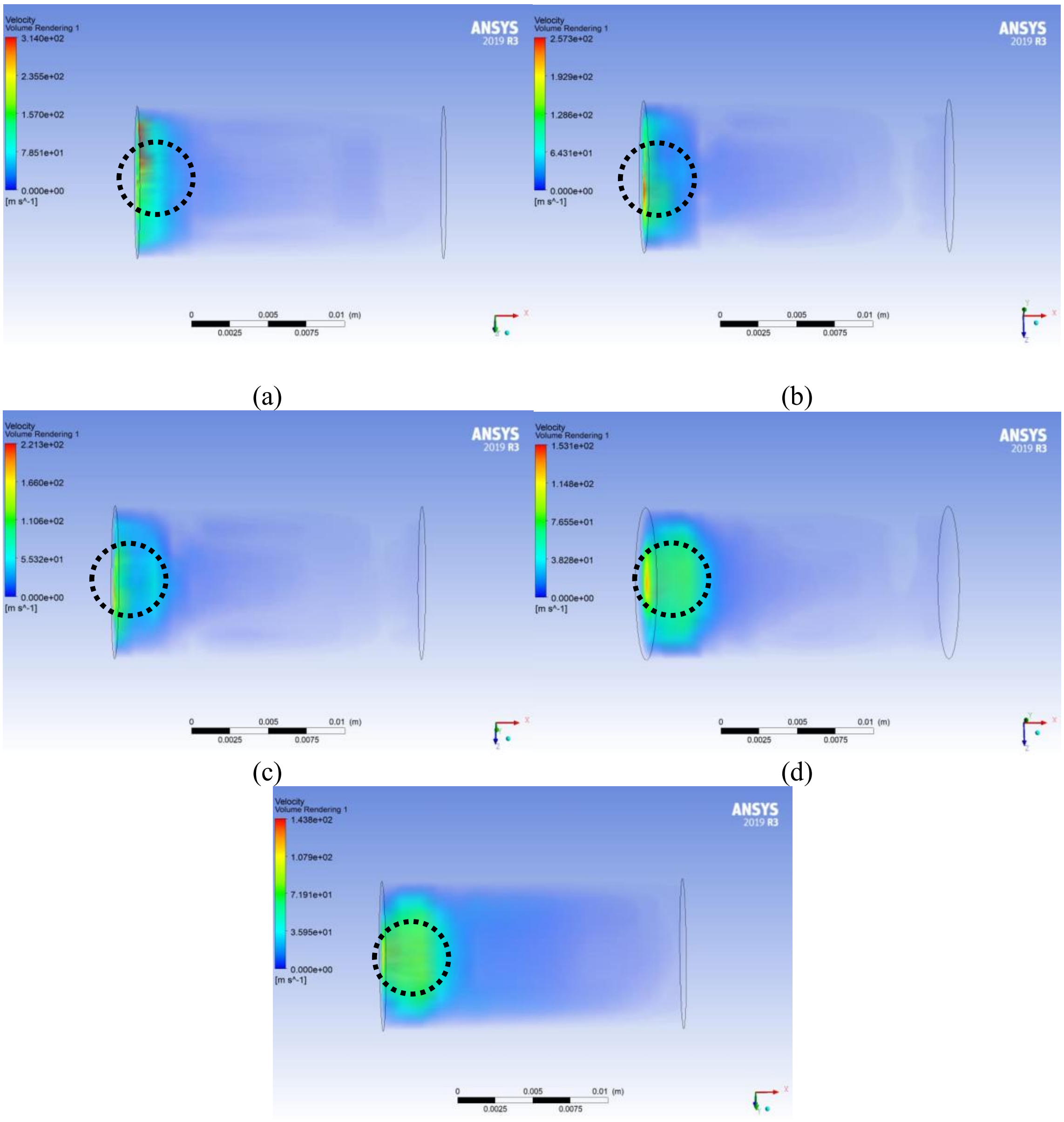


Figure 5. The results of the ANSYS simulation of the burning pellet rate in the variation of the mixture (gelam wood + rice husk): (a). 100% gelam composition, (b). Gelam composition 80%: Rice husk 20%, (c). 60% Gelam Composition: 40% Husk, (d) 50% Glam Composition: 50% Husk and (e). 100% Husk Composition

Combustion pressure affects the stability of the combustion process and combustion temperature [33], where the more evenly the combustion pressure, the better the combustion process. The effect of pressure on the combustion temperature is that when the air pressure is higher, the combustion temperature produced is more maximal. The simulation results show that the highest combustion air pressure occurs at 100% gelam composition (6.a) and the lowest at 100% husk composition (6.e). It shows that the addition of rice husk composition reduces the combustion pressure. It appears in the gelam composition of 100-60% (5a,b,c) the combustion pressure is high at the ends of the pellet (circle sign) in contrast to the case of 50-0% gelam composition (circle sign) the combustion pressure at the pellet tip begins to decrease (circle sign). The pressure on the 0% gelam pellet (5e) is the lowest (circle sign) so that on the pellet with 0%, the stability of the combustion process is disturbed so that the flame becomes unstable.

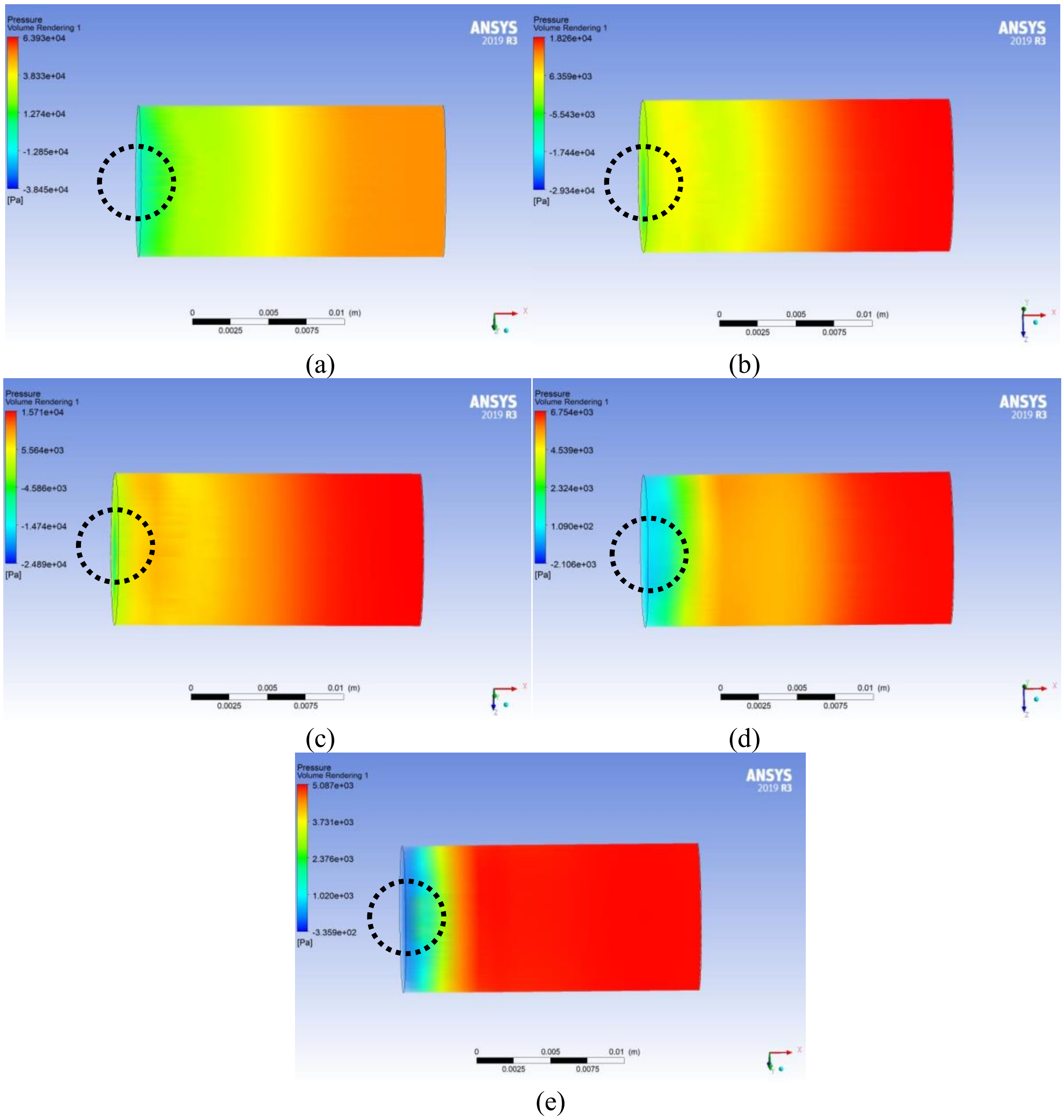


Figure 6. Simulation results of ANSYS Combustion pressure on the variation of the mixture (gelam wood + rice husk): (a). 100% gelam composition, (b). Gelam composition 80%: Rice husk 20%, (c). 60% Gelam Composition: 40% Husk, (d) 50% Glam Composition: 50% Husk and (e). 100% Husk Composition

4. Conclusions

The results of this study indicate: The addition of the percentage of gelam does not increase the combustion temperature as well as the addition of the percentage of rice husks; this is very beneficial when considering the lower calorific value of rice husks. In the increasing composition of rice husks, the combustion rate decreases; this is influenced by the calorific value of the pellets making up the material. Where the lower calorific value of rice husk affects the rate of combustion. Pellets with a large density affect the rate of pellet burning, thereby prolonging the burning time. The density of pellets is affected by the pressure of pellet molding; the greater the pressure makes the fuel denser and large density. The highest combustion air pressure occurs at 100% gelam composition and the lowest at 100% husk composition. It shows that adding rice husk composition reduces the combustion pressure and vice versa applies to adding gelam composition.

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References

[1] Amrullah, A., Syarief, A., & Saifudin, M. (2020). Combustion Behavior of Fuel Briquettes Made from Ulin Wood and Gelam Wood Residues. *International Journal of Engineering, Transactions B: Applications*, *33*(11), 2365–2371. https://doi.org/10.5829/ije.2020.33.11b.27.
[2] Rima Riyanti, Ulinnuha Latifa, Y. S. (2021). *Multitek Indonesia : Jurnal Ilmiah*. *6223*(January), 121–130.
[3] Schipfer, F., Kranzl, L., Olsson, O., & Lamers, P. (2020). The European wood pellets for heating market - Price developments, trade and market efficiency. *Energy*, *212*, 118636. https://doi.org/10.1016/j.energy.2020.118636.
[4] Vera, I., Goosen, N., Batidzirai, B., Hoefnagels, R., & van der Hilst, F. (2022). Bioenergy potential from invasive alien plants: Environmental and socio-economic impacts in Eastern Cape, South Africa. *Biomass and Bioenergy*, *158*(January), 106340.
[5] Siwale, W., Frodeson, S., Berghel, J., Henriksson, G., Finell, M., Arshadi, M., & Jonsson, C. (2022). Influence on off-gassing during storage of Scots pine wood pellets produced from sawdust with different extractive contents. *Biomass and Bioenergy*, *156*(December 2021), 106325. https://doi.org/10.1016/j.biombioe.2021.106325
[6] Arsad, E. (2014). SIFAT FISIK DAN KIMIA WOOD PELLET DARI LIMBAH INDUSTRI PERKAYUAN SEBAGAI SUMBER ENERGI ALTERNATIF (Carakteristic Physical and Chemistry of Wood pellet from Industrial Disposal of Wood as Sources Energy Alternatif). *Jurnal Riset Industri Hasil Hutan*, *6*(1), 1–8.
[7] Sylviani, & Suryandari, E. Y. (2013). Potensi Pengembangan Industri Pelet Kayu sebagai Bahan Bakar Terbarukan Studi Kasus di Kabupaten Wonosobo (Potential Development of Wood Pellets As Renewable Fuel, Case Study of Wonosobo District). *Penelitian Sosial Ekonomi Kehutanan*, *10*(4), 235–246.
[8] Girsang, M. A. P. (2019). *Analisa Karakteristik Bahan Bakar Alternatif Biopelet Dari Serbuk Kayu Dan Sekam Padi Terhadap Lama Waktu Pembakaran*. 1–18.
[9] Zadravec, T., Rajh, B., Kokalj, F., & Samec, N. (2022). The impact of secondary air boundary conditions on CFD results in small-scale wood pellet combustion. *Fuel*, *324*(PA), 124451. https://doi.org/10.1016/j.fuel.2022.124451
[10] Winaya, I. S., Sujana, I. G., & Tenaya, I. (2010). Formasi Gas Buang pada Pembakaran Fludized Bed Sekam Padi. *Jurnal Energi Dan Manufaktur*, *4*(1), 2–6.
[11] Sidabutar, V. T. P. (2018). Kajian Peningkatan Potensi Ekspor Pelet Kayu Indonesia sebagai Sumber Energi Biomassa yang Terbarukan. *Jurnal Ilmu Kehutanan*, *12*(1), 99. https://doi.org/10.22146/jik.34125
[12] Umrisu, M. L., Pingak, R. K., & Johannes, A. Z. (2018). Pengaruh Komposisi Sekam Padi Terhadap Parameter Fisis Briket Tempurung Kelapa. *Jurnal Fisika : Fisika Sains Dan Aplikasinya*, *3*(1), 37–42. https://doi.org/10.35508/fisa.v3i1.592
[13] Ulfa, D., Lusyiani, L., & A.R. Thamrin, G. (2021). KUALITAS BIOPELLET LIMBAH SEKAM PADI (Oryza sativa) SEBAGAI SALAH SATU SOLUSI DALAM MENGHADAPI KRISIS ENERGI. *Jurnal Hutan Tropis*, *9*(2), 412. https://doi.org/10.20527/jht.v9i2.11293
[14] Ciptaningtyas, Drupadi; Suhardiyanto, H. (2016). Ifat hermo isik rang ekam. *Sifat Thermo-Fisik*

Arang Sekam, *10*(2), 1–6.

[15] Bandara, J. C., Jaiswal, R., Nielsen, H. K., Moldestad, B. M. E., & Eikeland, M. S. (2021). Air gasification of wood chips, wood pellets and grass pellets in a bubbling fluidized bed reactor. *Energy*, *233*, 121149. https://doi.org/10.1016/j.energy.2021.121149

[16] Jeklin, A. (2017). Jurnal Ilmiah: Energi & Kelistrikan. *Sekolah Tinggi Teknik - PLN*, *9*(2), 1–23.

[17] Huang, X., Hu, Z., Miao, Z., Jiang, E., & Ma, X. (2020). Chemical looping gasification of rice husk to produce hydrogen-rich syngas under different oxygen carrier preparation methods. *International Journal of Hydrogen Energy*, *45*(51), 26865–26876. https://doi.org/10.1016/j.ijhydene.2020.07.116

[18] Gilvari, H., van Battum, C. H. H., van Dijk, S. A., de Jong, W., & Schott, D. L. (2021). Large-scale transportation and storage of wood pellets: Investigation of the change in physical properties. *Particuology*, *57*, 146–156. https://doi.org/10.1016/j.partic.2020.12.006

[19] Manatura, K., Lu, J. H., Wu, K. T., & Hsu, H. Te. (2017). Exergy analysis on torrefied rice husk pellet in fluidized bed gasification. *Applied Thermal Engineering*, *111*, 1016–1024. https://doi.org/10.1016/j.applthermaleng.2016.09.135

[21] Djomdi, Fadimatou, H., Hamadou, B., Nguela, L. J. M., Christophe, G., & Michaud, P. (2021). Improvement of thermophysical quality of biomass pellets produced from rice husks. *Energy Conversion and Management: X*, *12*, 100132. https://doi.org/10.1016/j.ecmx.2021.100132

[22] Mian, I., Li, X., Dacres, O. D., Wang, J., Wei, B., Jian, Y., Zhong, M., Liu, J., Ma, F., & Rahman, N. (2020). Combustion kinetics and mechanism of biomass pellet. *Energy*, *205*, 117909. https://doi.org/10.1016/j.energy.2020.117909

[23] Gungor, A. (2010). Simulation of emission performance and combustion efficiency in biomass fired circulating fluidized bed combustors. *Biomass and Bioenergy*, *34*(4), 506–514. https://doi.org/10.1016/j.biombioe.2009.12.016

[24] Saosee, P., Sajjakulnukit, B., & Gheewala, S. H. (2022). Environmental externalities of wood pellets from fast-growing and para-rubber trees for sustainable energy production: A case in Thailand. *Energy Conversion and Management: X*, *14*(December 2021), 100183. https://doi.org/10.1016/j.ecmx.2022.100183

[25] Giesen, W. (2015). Case Study: Melaleuca cajuputi (gelam) – a useful species and an option for paludiculture in degraded peatlands. Sustainable Peatlands for People & Climate (SPPC) Project. Wetlands International. p 16.

[26] Ramadhoni, F. (2016). Penebangan marak, hutan kayu gelam di Muba berkurang. Sriwijaya Post.

[27] Alpian, Prayitno, T.A., Sutapa, J.P.G. & Budiadi. (2014). Kualitas asap cair batang gelam (Melaleuca sp.). Jurnal Penelitian Hasil Hutan, 32(2), 83-92. https://doi.org/10.20886/jphh.2014.32.2.83-92

[28] Herry Irawansyah, Andy Nugraha, Moh Noer Afifudin, Muhammad, & Rizqi Nor Al'Arisko. (2022). Pengaruh Variasi Ukuran Serbuk (Mesh) Dan Persentase Perekat Tapioka Terhadap Sifat Fisik Pellet Kayu Gelam. Multitek Indonesia: Jurnal Ilmiah. Volume: 15 No. 2, Hal. 13 - 22. Doi : 10.24269/mtkind.v15i2.4194

[29] Dwi Rasy Mujiyanti, Dahlena Ariyani, Nurul Paujiah, Muna Lisa, & Rizky Pradana N.E. (2021). Isolasi Dan Karakterisasi Abu Sekam Padi Lokal Kalimantan Selatan Menggunakan FTIR Dan XRD. Prosiding Seminar Nasional Lingkungan Lahan Basah. Volume 6 Nomor 2.

[30] Nasukhah, Awal Laili Yuanita and Mahardhika, Aditya Yusuf. (2018). *Pengaruh Massa Jenis Briket Arang Tempurung Kelapa Terhadap Waktu Pembakaran dan Konversi Panas Menjadi Listrik Menggunakan Thermoelectric Converter (TEC). Sarjana thesis, Universitas Brawijaya.*

[31] İsmail Özlüsoylu, Abdullah İstek, 2019, The Effect of Hybrid Resin Usage on Thermal Conductivity in Ecological Insulation Panel Production, 4th International Conference on Engineering Technology and Applied Sciences (ICETAS) April 24-28 2019 Kiev Ukraine.

[32] A Syarief, A Nugraha, M N Ramadhan, Fitriyadi, and G G Supit. (2021). The Effect Of The Percentage Of Alaban Waste And Rice Husk Waste With Tapioca Adhesive On The Physical

Properties. IOP Conf. Series: Earth and Environmental Science. doi:10.1088/1755-1315/758/1/012019.
[33] Gilang Wahyu Ramadhan, Basyirun, 2020, Pengaruh Tekanan Udara Terhadap Temperatur Pembakaran Oli Bekas pada Kompor, JURNAL DINAMIKA VOKASIONAL TEKNIK MESIN 5(2):163-168 DOI: 10.21831/dinamika.v5i2.34804